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CERTIFICATION

I, the below named translator, hereby declare that: my name and post office address are as stated below; that I am knowledgeable in the English and German languages, and that I believe that the attached text is a true and complete translation of PCT/EP2004/052755, filed with the European Patent Office on November 2, 2004.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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METHOD FOR OPERATING A FREQUENCY CONVERTER CIRCUITDescription

[001] Method for operating a frequency converter circuit

[002] The present invention relates to a method for operating a frequency converter circuit comprising at least two outputs that are respectively connected to a load, especially an induction coil, wherein a first output is operated at a first switching frequency and a second output is simultaneously operated at a second switching frequency that is different from the first in such a way that noise having a frequency generated by the superposition of the first switching frequency and the second switching frequency is produced.

[003] Modern induction cooking surfaces are usually equipped with two or four induction cooking zones. The induction cooking zones have induction coils which are supplied with high-frequency operating currents by means of converter circuits. It is known to operate two induction coils jointly by means of one converter circuit with two outputs, each of the outputs being connected to an induction coil. Various procedures have been proposed for avoiding or reducing noise when both outputs are operated simultaneously.

[004] Known from DE 196 54 268 C2 is a method for operating the converter circuit where both outputs of the converter circuit are operated in time multiplex so that no noise can occur. The disadvantage of this method is that elaborate triggering and over-dimensioning of the power electronics is required.

1  
2 [005] If the outputs are not operated in time multiplex and  
3 the two induction coils are supplied simultaneously with  
4 operating currents at different frequency, noise is  
5 produced. It is known to reduce this noise by means of  
6 choking coils connected in series to the induction coil.  
7 The disadvantage of this method is that the method is not  
8 always stable. In addition, the noise can only be damped  
9 and the choking coils are required as additional components,  
10 making the converter circuit more elaborate.

11  
12 [006] It is the object of the invention to provide an  
13 improved and cost-effective method for operating a converter  
14 circuit comprising at least two outputs, especially for an  
15 induction cooking surface.

16  
17 [007] This object is solved by a method for operating a  
18 converter circuit having the features of claim 1.

19  
20 [008] In a converter circuit comprising at least two outputs  
21 that are respectively connected to a load, especially an  
22 induction coil, a first output is operated at a first  
23 switching frequency and a second output is simultaneously  
24 operated at a second switching frequency that is different  
25 from the first. In this way noise having a frequency  
26 generated by the superposition of the first switching  
27 frequency and the second switching frequency is produced.  
28 The converter circuit is operated in such a way that the  
29 frequency of the noise is lower than a first cut-off  
30 frequency and/or higher than a second cut-off frequency.  
31 This procedure has the advantage that noise can be produced  
32 at a frequency that lies outside the human audible range by  
33 appropriately selecting the first cut-off frequency and the  
34 second cut-off frequency. Furthermore, the induction coils

1 can be operated at frequencies at which a high efficiency  
2 can be achieved. In addition, additional components such as  
3 choking coils for reducing the noise can be dispensed with.  
4

5 [009] According to a preferred embodiment, it is provided  
6 that the first switching frequency and/or the second  
7 switching frequency are operated in such a way that the  
8 frequency of the noise is lower than the first cut-off  
9 frequency and/or higher than the second cut-off frequency.

10 The switching frequencies of the outputs can be simply  
11 adapted by means of intelligent power switches.  
12

13 [010] Advantageously an electrical power of at least one of  
14 the outputs is regulated by means of a relative switch-on  
15 time and/or the switching frequency. Thus, the converter  
16 circuit can be operated with the induction coils in such a  
17 way that a high efficiency is achieved.  
18

19 [011] According to a preferred embodiment, it is provided  
20 that the first cut-off frequency and/or the second cut-off  
21 frequency are determined depending on a level of the noise.  
22 In this way, the cut-off frequencies can be adapted to the  
23 human audibility threshold so that the noise cannot be  
24 perceived.  
25

26 [012] In particular, the first cut-off frequency and/or the  
27 second cut-off frequency are determined depending on a total  
28 electrical power of the outputs. The level of the noise  
29 depends on the total electrical power of the outputs and the  
30 total electrical power can easily be determined. In this  
31 way, the cut-off frequencies can be adapted especially  
32 easily to the human audibility threshold.  
33

1 [013] According to a preferred embodiment, it is provided  
2 that the first cut-off frequency is 2 kilohertz and/or the  
3 second cut-off frequency is 14 kilohertz. For these cut-off  
4 frequencies the human audibility threshold is very high so  
5 that the level of the noise does not reach the human  
6 audibility threshold or only insignificantly exceeds it.

7  
8 [014] In particular, the invention relates to an induction  
9 cooking device such as, for example, an induction cooking  
10 surface or a cooker with an induction heating element.

11  
12 [015] The invention and its further developments are  
13 explained in detail hereinafter with reference to drawings:

14  
15 [016] In the figures

16  
17 [017] Fig. 1a is a first embodiment of a converter circuit,

18  
19 [018] Fig. 1b is a second embodiment of a converter circuit,

20  
21 [019] Fig. 2 is a schematic diagram of possible noise  
22 frequencies during operation of the converter circuits  
23 according to Figure 1,

24  
25 [020] Fig. 3 is a schematic profile of the human audibility  
26 threshold,

27  
28 [021] Fig. 4 is a schematic time profile of a period of an  
29 output voltage of the converter circuits according to Figure  
30 1 and

31  
32 [022] Fig. 5 is a schematic diagram of an adaptation of  
33 electrical output powers for the converter circuits

1 according to Figure 1 taking into account a first and a  
2 second cut-off frequency.

3  
4 [023] Figures 1a and 1b are schematic diagrams showing two  
5 different embodiments of a converter circuit comprising two  
6 outputs or induction coils. Here V designates a voltage  
7 source, I1 is a first and I2 is a second induction coil, S1,  
8 S2, S3 and S4 are high-frequency switches, CF1 and CF2 are  
9 capacitive input filters and C1+, C1-, C2+ and C2- are  
10 capacitors. The second embodiment (Fig. 1b) differs from  
11 the first embodiment (Fig. 1a) in that two changeover  
12 switches R1, R2 are provided for reconfiguring the topology  
13 for the case when both induction coils I1, I2 are not  
14 switched on or both outputs are not active.

15  
16 [024] Figure 2 shows a schematic diagram of possible  
17 frequencies of the noise during operation of the converter  
18 circuits according to Figure 1a or 1b. The first induction  
19 coil I1 is operated at a first switching frequency f1 and  
20 the second induction coil I2 is operated at a second  
21 switching frequency f2 which is higher than the first  
22 switching frequency f1. Both switching frequencies f1, f2  
23 lie above a maximum frequency  $f_{\max}$  which can be perceived by  
24 human hearing. In this way, noise produced at the switching  
25 frequencies f1 and f2 cannot be heard by humans. As a  
26 result of a superposition of the two switching frequencies  
27 f1, f2, further noise is produced, for example, at a  
28 frequency fS which corresponds to a difference comprising  
29 the second switching frequency f2 minus the first switching  
30 frequency f1. This frequency fS can lie in a frequency band  
31 B which indicates the frequencies perceptible by humans.  
32 The noise can have different levels L1, L2, LS at different  
33 frequencies f1, f2, fS which is indicated by arrows of

different length at the frequencies  $f_1$ ,  $f_2$  and  $f_S$  in Figure 2.

[025] Figure 3 shows a schematic profile of the human audibility threshold  $H$ . Depending on the frequency  $f$ , a different minimum noise level  $L$  can be perceived by the human hearing which is indicated by the profile of the audibility threshold  $H$  in Figure 3. A first cut-off frequency  $g_1$  and a second cut-off frequency  $g_2$  are determined using the level  $L_S$  of the noise and its points of intersection with the profile of the audibility threshold  $H$ , the first cut-off frequency  $g_1$  being lower than the second cut-off frequency  $g_2$ . The converter circuits according to Figure 1a and 1b are operated according to the invention so that the frequency  $f_S$  of the noise is lower than the first cut-off frequency  $g_1$  or higher than the second cut-off frequency  $g_2$ . In this way the noise is outside the human hearing range and thus cannot be perceived. The level  $L_S$  of the predicted noise can, for example, be estimated using the switching frequencies  $f_1$ ,  $f_2$  and the electrical powers  $P_1$  and  $P_2$  supplied to the induction coils. Alternatively, experimental cut-off frequencies  $g_1$ ,  $g_2$  can be defined, for example, the first cut-off frequency  $g_1$  at 2 kilohertz and the second cut-off frequency  $g_2$  at 14 kilohertz.

[026] Parameters for adapting the electrical powers  $P_1$ ,  $P_2$  supplied to the induction coils  $I_1$ ,  $I_2$  are firstly the switching frequencies  $f_1$ ,  $f_2$  and secondly a relative switch-on time  $D$ . Figure 4 shows a schematic time profile of a period of a first output voltage  $U_A$  of the converter circuit according to Figure 1a and 1b. The period  $1/f$  is normalised to unity in Figure 4. The output voltage  $U_A$  increases during the relative switch-on time  $D$  and then decreases slowly again. The electrical powers  $P_1$ ,  $P_2$  supplied to the

1 induction coils I1, I2 are highest for relative switch-on  
2 times D of 0.5.

3  
4 [027] Figure 5 shows a schematic diagram of an adaptation of  
5 the electrical output powers P1 and P2 for the two induction  
6 coils I1, I2 according to the converter circuits from Figure  
7 1a and 1b taking into account the two cut-off frequencies g1  
8 and g2. For the first induction coil I1, for example, which  
9 requires the higher electrical power P1 of the two induction  
10 coils I1, I2, the switching frequency f1 is specified as 21  
11 kilohertz for example and the relative switch-on time D is  
12 specified as 0.5. The electrical power P2 for the second  
13 induction coil I2 is now adjusted by means of the relative  
14 switch-on time D and by means of the switching frequency f2  
15 taking into account the two cut-off frequencies g1 and g2.  
16 The second switching frequency f2 can lie in a range between  
17 the first switching frequency f1 (here 21 kilohertz) and the  
18 sum of the first switching frequency f1 and the first cut-  
19 off frequency g1 (here 23 kilohertz) and above the sum of  
20 the first switching frequency f1 and the second cut-off  
21 frequency g2 (here 35 kilohertz). In this way it is ensured  
22 that the noise at the frequency fS which is produced from  
23 the difference between the second switching frequency f2 and  
24 the first switching frequency f1 is not perceived by the  
25 human hearing.

|    |       |   |
|----|-------|---|
| 1  | [028] | Reference list  |
| 2  | [029] | B frequency band  |
| 3  | [030] | C1+ capacitor   |
| 4  | [031] | C1 capacitor  |
| 5  | [032] | C2+ capacitor   |
| 6  | [033] | C2 capacitor  |
| 7  | [034] | CF1 capacitive input filter                             |
| 8  | [035] | CF2 capacitive input filter                             |
| 9  | [036] | D relative switch-on time                               |
| 10 | [037] | f frequency   |
| 11 | [038] | $f_{\max}$ maximum frequency perceived by human hearing |
| 12 | [039] | f1 switching frequency of the first induction coil      |
| 13 | [040] | f2 switching frequency of the second induction          |
| 14 |       | coil  |
| 15 | [041] | fS frequency of the noise                               |
| 16 | [042] | g1 first cut-off frequency                              |
| 17 | [043] | g2 second cut-off frequency                             |
| 18 | [044] | H audibility threshold                                  |
| 19 | [045] | I1 first induction coil                                 |
| 20 | [046] | I2 second induction coil                                |
| 21 | [047] | L sound level   |
| 22 | [048] | L1 sound level at the first switching frequency         |
| 23 | [049] | L2 sound level at the second switching frequency        |
| 24 | [050] | LS level of noise at fS                                 |
| 25 | [051] | P electrical power                                      |
| 26 | [052] | P1 electrical power of the first induction coil         |
| 27 | [053] | P2 electrical power of the second induction coil        |
| 28 | [054] | R1 changeover switch                                    |
| 29 | [055] | R2 changeover switch                                    |
| 30 | [056] | t time  |
| 31 | [057] | U voltage   |
| 32 | [058] | UA output voltage                                       |
| 33 | [059] | V voltage source  |